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A PETROGRAPHIC STUDY OF THE MERCHANTVILLE CLAY OF CAMDEN AND BURLINGTON COUNTIES, NEW JERSEY, AND ITS STRATIGRAPHIC SIGNIFICANCE

PAUL JENNINGS STORM

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A THESIS

IN GEOLOGY

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

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INTRODUCTORY

The object of this investigation is to determine the mineral composition of the Merchantville Clay, and nature and origin of its component mineral grains, and to infer from a study of these grains and from field relations, the conditions under which this formation was laid down.

The term "clay" suggests to most people a substance which is more or less even grained, homogeneous in nature, and appears to the unaided eye to consist of one simple substance. However, when many of our clays are subjected to careful mechanical separation and examination under the microscope they are found to be highly complex substances. They usually consist of mineral grains, varying considerably in size, set in a fine-textured mass of so-called "clay substance" or "clay paste."

The "clay paste" is in itself very complex in nature, normally structureless in appearance, until under high power magnification it is seen to consist of a roughly organized development of crystalline aggregates, often deeply colored, almost opaque, and sprinkled with minute dust particles, which seem to include iron ores, carbonaceous specks, and rutile. The "clay paste" also includes one or more hydrous aluminous silicate minerals.* Some of the material of the "clay paste" is colloidal in nature, and on the percentage of colloidal material present depends, in a great measure, the plasticity of the clay.

Among the coarse mineral grains set in the fine mass of the clay substance we find fragments of quartz, feldspar, mica, hornblende, garnet, magnetite, glauconite, etc., etc. In fact nearly every common mineral found in quantities in rocks is likely to appear at one time or another in clays.

The Merchantville Clay which is the subject of this study conforms very well to the above generalized description of clays in general. One outstanding difference from other clays is in the large amount of glauconite which the Merchantville usually contains, and which will be discussed further on in this paper.

In order to separate the constituent particles of a clay for study some mechanical means of separation must be adopted, and elutria-

*Milner, H. B., Sedimentary Petrography. 1929 edition, p. 288.

tion was the method decided on as being the most practicable for very fine sediments. In this method of separation the particles are subjected to moving currents of water whose velocity is so varied by the size and shapes of the vessels through which the water passes that particles of different size settle out in each vessel, the size depending upon the velocity of the current in the vessel.

The apparatus used in this investigation was the type known as Koebel's elutriator, which consists of four conical glass jars with inlets at the bottom and outlets at the top. These are connected with rubber and glass tubes, the outlet of one jar with the inlet of the next. The jars vary in size, from a small one with a sharply tapering conical outline at the inlet end of the series to a large jar with a gently tapering conical outline at the outlet end. The sediment to be separated into grade sizes is placed in the small jar where the narrow, tapering cone gives the water a high velocity. The largest and heaviest grains are retained in the first jar, while the remaining material is washed over into the second jar where it is subjected to a more slowly rising current. These four jars give four grade sizes, and by catching some of the finest material which escapes from the outlet of jar No. 4, it is possible to obtain a fifth grade size whose quantity can be estimated by difference. The clay colloid also escapes here along with the finest silt, which is around .03 mm. and less in diameter.

For extreme accuracy in elutriation it is desirable that the water be always at the same temperature, as its viscosity decreases rapidly with rise of temperature and cold water will therefore move larger grains than warm water, other conditions being equal.* No means was available in the laboratory where this investigation was carried on to so control the temperature of the water, and in the writer's opinion the amount of daily variation was not sufficient to greatly affect the results.

The microscope with micrometer eyepiece was used to calibrate the elutriator, and determine the size of the different grades separated in each vessel. Pressure and velocity were maintained at a constant value throughout the duration of the work by feeding water to the

*Boswell, P. G. H., Memoir on British Resources of Refractory Sands. Taylor and Francis. London, 1918.

elutriator system by means of a small constant-level reservoir.

An objection to calibrating grade sizes by means of the micrometer eyepiece is that the average diameter of grains obtained in this way has usually too high a value. The grains are seldom true spheres, and tend to lie in their flattest position. Hence the smallest diameter is not measured.* Therefore all diameters of grains expressed in the graphic diagrams to be found at the end of this paper are probably a little too high, but this unavoidable error was reduced to a minimum by taking careful measurements under the microscope of about ten grains in each grade size sample, and measuring them in their longest and shortest visible diameters. Then these ten grains were averaged to get the final average diameter for that grade size. The grade sizes are as follows:

Grade Size No.	Obtained from Elutriator Jar No.	Average Diameter in mm.
1	1	.3 mm. and over
2	2	Less than .3 mm. and over .2 mm.
3	3	Less than .2 mm. and over .16 mm.
4	4	Less than .16 mm. and over .12 mm.
5	overflow of jar 4	Less than .12 mm. and over .02 mm. (Grade size No. 5 also includes the colloidal material, and any grains less than .02 mm.)

For a further discussion of elutriation and descriptions of elutriation apparatus see the list of writings referred to below.†

The quantitative results of the mechanical analyses by elutriation are represented by using the so-called "butterfly" diagrams or "strip" diagrams first devised by J. A. Udden.‡ While some authors§ recommend the graph or curve diagrams for representing results

*Boswell, P. G. H., op. cit.

†Boswell, P. G. H., A Memoir on British Resources of Refractory Sands. London, 1918; Taylor and Francis. Stadler, H., Grading Analyses by Elutriation. Trans. Inst. Mining and Metall. XXII (1912-13) p. 686. Ries, H., Clays, Their Occurrence, Properties and Uses. 1908, 2d ed. Keilhack, Lehrbuch der praktischen Geologie. 1908, 2d ed., Stuttgart.

‡Udden, J. A., The Mechanical Composition of Wind Deposits. Augustana Library Publ. No. 1, 1898.

§Boswell, P. G. H., op. cit., p. 29.

of mechanical analyses of sediments the writer believes that the "strip" diagram is easier and quicker to read and interpret, and more easily comprehended by the average reader. In this type of diagram each grade size separated is allowed a separate vertical column. The vertical distance marked off in black represents the percentage of a given grade size in the entire sample. It will be noted that five grade sizes are accounted for, the percentages being determined by weight. For the exact diameters of the five grade sizes see table on preceding page.

The amount of No. 5 grade size collected from the overflow was obtained by adding up the weights of sediment from Jars 1, 2, 3 and 4 and subtracting the result from the total weight of the sample. This gave the amount of material which escaped through the overflow. A small sample was collected for examination and the rest allowed to escape. When elutriation was completed the samples were removed from the elutriator, dried in an evaporating dish over a gas flame, and weighed.

Great difficulty was experienced in disintegrating the clay samples properly in order that elutriation could be carried out to completion. Opinions differ as to the best means of accomplishing this but in general the method was that described by M. I. Goldman in his work on the Upper Cretaceous Sediments of Maryland.*

The clay sample after being weighed, was placed in water and gently boiled for fifteen minutes. Some writers say that only lukewarm water should be used, as hot water coagulates the clays. The writer found that boiling seemed to give the best results with the particular samples of clay he worked with, but whether it would do so with all clays is a disputed question.

The next step, after gently boiling the clay in water for fifteen minutes was to transfer the mixture of clay and water to a mechanical agitator, where it was agitated continuously for eight hours or more. The writer constructed an agitator quite easily and cheaply by fastening a flat board on the end of a shaft so that it revolves with the shaft, and then fastening two fairly large chemical wash bottles to the board with their long axes perpendicular to the revolv-

*Goldman, M. I., Petrography and Genesis of the Sediments of the Upper Cretaceous of Maryland. Baltimore, The Johns Hopkins Press, 1916.

ing shaft. The apparatus must be geared down so as to revolve quite slowly and then the clay, together with a little water, will splash from one end of the bottle to the other and be subjected to a disintegrating action.*

After eight hours or more of agitation the sample was transferred to the elutriator and elutriation commenced. The writer noted that in some samples, especially in the "fat" (high colloid content) clays that there were sometimes oval lumps of clay matter present in the sample even after a long time in the agitator. Goldman has recorded the same fact and he likewise suggests that in some cases the clay balls are an essential part of the sediment, representing some sort of concretion-like growth in the clay, since he found under the microscope round, clay-like granules with a faint aggregate polarization, which were believed to represent a state intermediate between clay and glauconite.†

In some of the clay samples these small, oval lumps persisted during elutriation. They were composed of fine material, some of which appears under the microscope to be the so-called "clay paste" with a more or less granular structure and soft, wax-like consistency. The lumps also included some of the very finest mineral grains, among which could be identified mica and quartz. Other very small mineral grains were present but their size made identification uncertain. Only the very finest mineral grains were present; the larger grains of quartz, glauconite, etc., were never found in the lumps.

In a few cases it was possible by running another test on a sample and boiling and agitating for a longer time, to reduce the tendency to lump somewhat. In other samples, however, further treatment was of no use; the lumps still persisted, and where such was the case the fact is noted in discussing the relative percentage of the different grade sizes in the sample.

In some samples the separation was clean from the beginning, so few lumps forming that they would not have an appreciable effect on the analysis. This was the case with the sandy clays and to a lesser degree with the clays that, although not sandy, were "lean," indicating a lower colloid content. The "fat" or high colloid sam-

*This method of making a cheap and quite efficient agitator was described by M. I. Goldman, op. cit., p. 116.

†Goldman, M. I., op. cit.

ples gave the most trouble.

It might be well to add here that the Merchantville clay is a geological formation which is not yet mineralogically stabilized. It is a soft, unconsolidated material; the colloid content varies both vertically in a section, and horizontally, in at least one instance, in a given bed. The glauconite is found to be in different stages of alteration in different layers; in some layers it has advanced well toward the limonite stage, while in other layers it appears fresh and green, with scarcely a suggestion of change.

DISCUSSION OF SAMPLES

Note: These samples are arranged and discussed in order and sequence from the top of the formation toward the bottom.

The term "muscovite" in these analyses has been used in the sense of white mica.

SAMPLE I.

Graham's Brick Yard, Lenola, N. J.
Uppermost 3 ft. at top of pit.

Appearance: A yellow sandy clay loam with some gravel. Gravel was from about ¼" to 1" in diameter.

Weight of sample for elutriation.....23.455 grams.

Percentage of grade sizes—(See also strip diagram: Sample I, Lenola).

Grade size number one.....	4.32	grams,	or	18.46%
" " " 2	.052	"	"	.00221%
" " " 3	.580	"	"	2.477%
" " " 4	1.821	"	"	7.764%
" " " 5	16.682	"	"	71.131%

Mineral content: (Listed in order of abundance) Quartz, mica, feldspar, glauconite, magnetite, ilmenite, possibly ilmenite altering to leucoxene, chromite, tourmaline.

Discussion—

Many of the larger grains of quartz were quite well rounded and had frosted surfaces which would indicate wind action. These were confined to Grade Size No. 1, while the smaller quartz grains in Size No. 4 were all angular. Likewise, not all of the grains in Size No. 1 were rounded, the majority of them being sub-angular.

Of note in this sample was the appearance in Size No. 1 of three grains of quartz which were sub-angular with extremely flat surfaces. The surfaces were somewhat frosted, and the grains give every indication of having been transported by ice and slightly wind-worn afterward. This might be expected considering the position from which the sample was collected. It was a part of the soil cap overlying the Merchantville, and although at the particular spot where it was obtained it passed gradually down into the clay below, about fifty feet away a distinct but not pronounced surface of unconformity was visible. The unconformity was not evident at the point where the sample was taken; here the soil merged gradually into the underlying clay. This sample belongs to the soil cap which directly overlies the Merchantville in some localities, and which is said by the U. S. Geological Survey to be of Quarternary age.* By far the majority of the quartz is subangular and some grains are deeply iron stained, while others are perfectly clear. Hydrochloric acid was applied to some of the iron-stained material and on some of the grains the stain was found to be permanent. This suggests at least two sources for the quartz grains; one source yielded permanently iron-stained material, and the other source clear material.

Feldspar was present, but was estimated to compose not more than a scant ten per cent of the total sample. Most of the feldspar was plagioclase. From the color it appeared to be oligoclase. One grain of orthoclase was noted. Some of the feldspar fragments were sharp edged, but the majority had slightly rounded edges.

The mica, which was almost entirely muscovite, concentrated in Grade Size No. 3. There was, as usual, much mica in the fine-grained material of Grade 5, which also appeared to be muscovite.

Glauconite was present but very scarce, estimated at not more than 10% of the whole. A noteworthy fact about this glauconite

*U. S. G. S. Folio of the Philadelphia Region.

was that the grains all had an even, fresh green color, and were nearly all of an elongated oval shape.

The fresh, oval-shaped glauconite grains are strikingly different in appearance from the general run of glauconite in the Merchantville samples, and suggest a different origin. It is persistent in every grade size, except No. 5, although in very small quantities.

According to L. Cayeux* both fresh and limonitised glauconite may be present in arable soil, owing its formation to adsorption of potassium compounds in this environment, the adsorptive media being soluble (colloidal) silica and colloidal ferric hydroxide. That the glauconite in this sample may have been derived in this way the writer suggests as a likely possibility.

Magnetite was present in each grade size to the extent of from one to ten grains. Ilmenite was present in even smaller amounts and a black mineral tentatively identified as chromite was present to the extent of four grains in grade size No. 4.

One small crystal fragment of tourmaline was present also in grade size No. 4. It was a fragment of a hexagonal prism with sharp edges and angles and crystal faces plainly showing.

The general resemblance of grade size No. 5 of this sample to typical loess from Iowa is noteworthy. The loess sample which was compared under the microscope with Grade No. 5 had less iron stain and no glauconite, and the quartz and muscovite grains in the loess were just a little smaller and more uniform in size. But one received the impression of examining two substances of a very similar nature. That wind work plays a part in modifying the present surface soils of Southern New Jersey is certain—might not the finer portions of this sample have been wind-deposited material? The wind-worn grains in grade size No. 1 suggest this also.

SAMPLE II.
Graham's Brick Yard, Lenola, N. J.
Next 3 ft. below Sample I.

Appearance: A yellowish clay, slightly stained with limonite. A

*L. Cayeux, Ann. Soc. Geol. du Nord, XXXIV, 1905, p. 146. Quoted by H. B. Milner, Sedimentary Petrography, p. 444.

few greenish splotches suggest the presence of glauconite without the aid of a lens.

Weight of sample for elutriation.....18.446 grams

Percentage by weight of grade sizes,

(See also strip diagram: Sample II, Lenola)

Grade size No. 1.....	5.920	grams	or	32%
Grade size No. 2.....	1.841	"	or	9.9%
Grade size No. 3.....	.016	"	or	8/100%
Grade size No. 4.....	.005	"	or	2/100%
Grade size No. 5.....	10.664	"	or	57.81%

Mineral content (Listed in order of abundance)—Quartz, muscovite, glauconite, chlorite, ilmenite, hornblende, garnet (rare), manganese nodules (rare), feldspar (rare).

In addition there were in grades No. 3 and 4 a few white, brown, and black organic fibers which were mentioned by Goldman as being of frequent occurrence in clays.*

The total glauconite in this sample was 22%, by weight, of the whole sample. The glauconite was extracted by means of a powerful electromagnet designed especially for work on fine mineral grains. The magnet was made according to the specifications set forth by Holmes in his "Petrographic Methods and Calculations."† In using the magnet it was found that very good results could be obtained in separating the glauconite from the coarser grade sizes, but in grades 3 and 4 much non-magnetic fine material was picked up along with the magnetic grains, and magnetic treatment of grade 5 was out of the question. This did not matter materially in this investigation, since the magnet is here used only for the purpose of extracting glauconite, and miscroscope examination showed that there was no glauconite in any of the grade 5 material. The picking up of non-magnetic grains appeared to be caused by mechanical entangling of these fine grains with the magnetic ones, and also probably to cohesion. To make allowances for this a rough grain count estimate was made of the true glauconite percentage of grades 3 and

*Goldman, M. I., op. cit.

†Holmes, Arthur, Petrographic Methods and Calculations, p. 89.

4. Accurate results for grades 1 and 2 could be obtained by weighing the magnetic product directly.

The quartz in this sample again indicates two sources of derivation, as in Sample I. Most of the quartz grains were very clear, white, and sharply angular. Roughly 20% of them are iron-stained, milky, and from slightly subangular to quite subangular, with decidedly rounded edges. The angular grains must have traveled but a very short distance before coming to rest. They are clear, with scarcely a sign of cracks or fissures, and to the writer suggest a quartz-bearing igneous rock as their origin, rather than a metamorphic one. The granites and pegmatites of the Piedmont region might well have been their place of origin.

An unusual characteristic of this sample was the absence of any large flakes of mica in grade size No. 1. Muscovite was plentiful in the finer sizes, and is usually present in No. 1 size.

Feldspar is scarce in all the samples of the Merchantville which have been examined, but is even more rare in the bed represented by this sample.

SAMPLE III.
Graham's Brick Yard, Lenola, N. J.
Directly below Sample II.

Appearance: A glauconitic, greenish-yellow clay. Quite granular after air drying.
Weight of sample for elutriation.....28.436 grams
Percentage by weight of grade sizes.....(See also strip diagram: Sample III, Lenola.)

Grade size No. 1.....	14.781	grams	or	51.97%
Grade size No. 2.....	3.287	"	or	11.55%
Grade size No. 3.....	.037	"	or	3/100%
Grade size No. 4.....	.017	"	or	5/100%
Grade size No. 5.....	10.314	"	or	36.27%

Mineral content: (Listed in order of abundance) Quartz, glauconite, chlorite, muscovite, feldspar (fairly plentiful), hornblende,

ilmenite, magnetite, tourmaline, garnet (rare), manganese nodules (rare). A few visible lumps of fibrous-appearing clay matter.

Total glauconite in this sample was 33%.

The sample as a whole is liberally stained with limonite and many of the quartz grains are coated with the ocherous variety of this mineral. Also the lumps of finest silt material included in No. 5 grade size were cemented in part by limonite. In the strip diagram of this sample it will be noted that No. 1 grade size is unusually high, running slightly over 50% of the total. This is due partly to the rather high percentage of glauconite grains in this sample. These grains for the most part are large enough to be collected in the No. 1 jar of the elutriator. Another factor to be considered here is the lumping of the finest material into "clay balls" which was discussed at length in the introduction to this report. Therefore No. 1 grade size should be lowered somewhat and Nos. 3 and 4 raised, in order to give a more accurate picture of the distribution of grade sizes.

Much of the quartz is clear, fresh, and angular in appearance, and fragments of quartz crystals were seen which had clean-cut visible faces and angles. Likewise the tourmaline crystals found in grade sizes 1, 2 and 4 had clearly defined faces. This fact points again to derivation from a nearby source and not much water sorting after deposition on the sea floor.

Two grains of quartz possessed light steel gray, platy, metallic inclusions which appeared to be hematite. This points to a possible third source for quartz grains in addition to the two definite sources postulated in sample 2.

The glauconite in this sample varies in color from light to dark green, with shades of brownish and yellowish greens shown by the grains which have partially altered to limonite.* Most of the glauconite is in irregular, rounded lumps and botryoidal aggregates. There are a small number of grains with laminated structure and the appearance of a prismatic crystal. These grains have a tendency to cleave at right angles to the long axis of the "prism" and have been referred to as supposed crystals by Mansfield in his report on potash

*For a good discussion of the alteration of glauconite see L. Cayeux, Introduction a l'Etude Petrographique des Roches Sedimentaires, vol. I, p. 250. Paris, 1916.

in the New Jersey greensands.* According to A. Lacroix† glauconite probably crystallizes in the monoclinic system, without ever achieving its full crystalline form. The writer wishes to note here that these, we might say, pseudo-prismatic grains are quite plentiful throughout the Merchantville clay. In some layers they are very common, in others scarce, but a thorough search hardly ever fails to yield some of them.

These grains are generally of a soft and wax-like consistency, and can be easily split along the lines of their supposed cleavage. The flakes that split off bear a strong resemblance to chlorite, except that the color is more of a yellowish green than is usually found in chlorite. The writer believes that some of the material called "chlorite" in these analyses may be derived from this source.

Feldspar is more common in this sample than is usual in the Merchantville. That does not mean, however, that it makes up more than a fair ten per cent of the total mass of the sample. It is white, slightly iron stained, and not badly weathered. The grains show angles which are slightly rounded off by solution, as are the corners. It is certainly a plagioclase, and probably one of the more acid plagioclases.

Feldspar is not plentiful in any of the samples, and in some is practically non-existent. And almost all the grains show rounding of the edges and corners by solution; sometimes the original outline of the grain is entirely destroyed and it is identified as feldspar only by the lines of cleavage.

SAMPLE IV.
Graham's Brick Yard, Lenola, N. J.
Directly beneath Sample III.
Thickness varies from about 6 inches to about 1½ feet.

Appearance: Yellow and brown flakes and crusts; hard layers of what appears to be pure limonite; masses of clay and sand between

*Mansfield, G. R., Potash in the New Jersey Greensands. Bull. 727, U. S. Geol. Surv. 1922. Quoted by Twenhofel; Treatise on Sedimentation, p. 336.

†Quoted by L. Cayeux, op. cit., p. 241.

these layers cemented with limonite. This layer is called "iron ore" by the clay diggers.

Percentage by weight of grade sizes..... (See strip diagram: Sample IV, Lenola.)

(Note: The writer deems it no longer necessary to give weights in grams and percentages, since the relative percentage of the various grade sizes is shown on the strip diagrams).

Mineral content (Listed in order of abundance)—Glauconite, quartz, limonite, are very abundant. Muscovite, plagioclase, orthoclase, manganese nodules, magnetite, are present, but not abundant. Chlorite, hornblende, ilmenite, are very rare.

In studying the strip diagram of this sample the observer will note the unusually high percentage of grade size No. 1. This is due to the fact that some of the coarse grains separated were lumps of quartz and glauconite grains cemented by limonite, and which it was impossible to disintegrate with the process used on the remainder of the samples. In fact, disintegration was practically impossible without crushing the grains to powder, since the limonite which cements them is in part, at least, furnished by the decomposition of the glauconite grains themselves.

What appears to the eye as being solid crusts of limonite, the "iron ore bed" of the clay diggers, is seen under the microscope to consist of glauconite, quartz grains, and mica, with now and then grains of material corresponding in size to grade 5, all tightly cemented with limonite.

There are two kinds of limonite present: first the hard, dark brown limonite with a fairly high lustre on the surface; second, the yellow ocherous variety. The former occurs in thin seams and flakes; the latter more or less impregnates the whole mass of material.

The writer is convinced that a part, if not all, of the ocherous variety comes from the altered glauconite. He has observed under the microscope, gradual transitions from lumps of altered glauconite of a soft, waxy nature, into a mass of yellow, ocherous limonite. Accompanying this transition would be a change in color from the more or less dark green of fresh glauconite to brownish greens and browns, as the alteration progressed.

Even the hard, dark brown, high-lustre limonite occurring in thin

flakes and seams, is found in such intimate association with altered and partly altered glauconite that it is hard to believe that the limonite did not all come from the same source, namely, alteration of the glauconite.

An accurate glauconite percentage figure was almost impossible to achieve in this sample, as the magnet picked up grains of glauconite, and limonite, and likewise quartz, all cemented together. After magnetic separation of two of the grades which contained the highest quantity of material, and careful examination and estimates, the writer concluded that 50% of glauconite for the whole sample would be a conservative estimate.

The quartz again shows two main types of grains; one type is clear, with sharp edges, and includes a few crystal fragments with faces plainly visible. The other type is iron stained and slightly worn.

SAMPLE V.
Graham's Brick Yard, Lenola, N. J.
Directly beneath Sample IV.

Appearance: A greenish, sandy clay, containing ammonite fossils. Greenish when fresh, and sandy in appearance and feel.
Percentage by weight of grade sizes..... (See strip diagram, Sample V, Lenola)

Mineral content: (Listed in order of abundance) Quartz, glauconite, muscovite, are the most plentiful. Ilmenite, chromite (?) chlorite, and feldspar are scarce. Tourmaline crystal fragments and rods of chitinous substance are rare.

Total glauconite in this sample is about 37%. This is based on magnetic separations and careful estimates in the event that the magnet picked up some limonite with the glauconite.

This layer is quite rich in ammonite fossils at the Graham clay pit near Lenola, but so far as the writer knows ammonites have not been reported from any other diggings in this formation in the territory where this work was carried on.

The quartz grains are angular to subangular, with the more angular types predominating. Most of the grains are quite clear but a few are iron stained.

The glauconite grains are from a light olive green to a decidedly dark green, with some brownish grains due to incipient alteration. The ilmenite and chromite (?) fragments are somewhat worn, but decidedly not rounded. They do appear to have been subject to more wear than the quartz. An interesting feature of this sample, and of several other samples as well, is the presence of sharp, clear pieces of tiny tourmaline crystals. They show no signs of wear whatever, and certainly must have come from a quite near source.

Feldspar is very scarce, and among the few actual grains observed in grade size No. 3, all but one grain were plagioclase. From its color and cleavage this grain was identified as orthoclase; the other grains might have been oligoclase. The scarcity of orthoclase as compared to plagioclase has been noted in every sample where feldspar was observed, and checks with the statement of Goldman concerning the association of feldspars and glauconite.*

SAMPLE VI.
Graham's Brick Yard, Lenola, N. J.
Directly beneath Sample V, and they merge gradually into each other.

Appearance: Black to blue-black clay, rubbery when wet. When air dried it is dark gray. Very sticky and greasy when wet. A "fat" clay.

Percentage of grade sizes.....Not diagramed

Mineral content: The only essential differences in the mineral grain assemblages from those of Sample V were the relative abundance of muscovite in this sample, and the almost total absence of limonite. The glauconite was estimated at 35%. The glauconite here is not changing to limonite, or at least has not gone far enough in the process to show any suggestion of brown or yellow in any of the grains.

This clay is of such a high colloidal content, and so difficult to elutriate on account of lumps forming that no diagram was attempted. Three separate tests were made with this material, using various modifications of the disintegrating treatment, but with no

*Goldman, M. I., op. cit., p. 181.

success. The mineral examination of the grade sizes was carried on as usual, but the mechanical separation was a failure in so far as accuracy was concerned, since the lumps of fine-grained material persisted throughout the elutriation process.

The extremely dark color of this clay suggests a large amount of organic matter. On putting a small piece into distilled water tiny bubbles were given off, and an odor of decay like that prevailing in a stagnant marsh was noted. When some of this clay was heated in a crucible it turned, on cooling, to a pinkish color, showing that the organic matter had burned off and that there was probably some iron present, although it was not noticed under the microscope as visible limonite.

SAMPLE VII.
Graham's Brick Yard, Lenola, N. J.
Next 2½ feet below Sample VI.

Appearance: A black clay, but not quite so intensely black as Sample VI, and not quite so sticky when moist. After air drying is of a greenish gray color, slightly stained with limonite.
Percentage of grade sizes. . . See strip diagram, Lenola, Sample VII.

Mineral content: (Listed in order of abundance) Quartz, glauconite, muscovite, abundant; chlorite, feldspar, limonite flakes, scarce; hornblende, ilmenite, tourmaline, zircon, asbestos (?), relatively rare. Organic fibers quite common in grade size No. 4.

Total glauconite percentage in this sample was 20%.

The quartz grains were mostly angular and clear, with relatively few iron stained ones.

The glauconite grains showed signs of wear, and were of various shades of green, some of them yellowish green.

The feldspar-quartz ratio in grade size No. 1 was unusually high, estimated by grain count to be 15:85. No orthoclase was seen. The feldspar showed evidence of deep decay along cracks, but no green color to denote the formation of glauconite in these cracks, which has been noted by L. Cayeux and others, was seen.

A few bits of chitinous material were noted, and something which resembled chitin, but from the shape of fragments could very easily

have been shell matter stained brown.

SAMPLE VIII.
Graham's Brick Yard, Lenola, N. J.
Next 4 feet below Sample VII.
VII and VIII are very similar.

Appearance: A dark, blue-black clay when moist. Greenish gray when dry.

Percentage of grade sizes. . . See strip diagram, Lenola, Sample VIII.

Mineral content: The minerals of this clay are not enough different from those of Sample VII to merit discussion. Total glauconite is about 17% of the whole sample.

Tests showed organic matter and iron present, as mentioned in connection with Sample VI.

SAMPLE IXa.
Graham's Brick Yard, Lenola, N. J.
Last 14 inches to bottom of pit.
Directly beneath sample VIII.

Appearance: Black clay, air dries to a greenish gray.

Percentage of grade sizes. . . See strip diagram, Lenola, Sample IXa.

Mineral content: Similar to VII and VIII above.

Total glauconite in this sample was 30% of the whole.

The glauconite was fairly even in color, a fairly dark green, and none of it suggested by its appearance any alteration taking place. The glauconite grains in grade size No. 3 were somewhat worn, but not altered.

This sample was not as "fat" as Sample IXb, at the same level in the pit. IXa resulted in a good separation, and was quite easily treated, which was not the case with IXb.

SAMPLE IXb.
Graham's Brick Yard, Lenola, N. J.
At the same level as Sample IXa, but about 12 feet away.

Appearance: A dark blue-black clay, with a greenish cast, when fresh and moist. Air dries to a dark gray.
Percentage of grade sizes.....Not diagramed.

Mineral content: Not carefully determined. Essentially the same general character as the three preceding samples.

This sample gave an unusual amount of trouble in disintegrating and elutriating; in fact, lumps formed so persistently and would not yield to any variation of the disintegrating treatment, (and several were tried) that it was thought useless to spend any more time on this sample. Examination of the poorly separated product under the microscope showed that the essential character of the minerals in this clay was like those preceding it.

This sample, however, taken in conjunction with sample IXa, which was much less "fat," or in other words, lower in colloidal content, does indicate that the colloidal content of these clay beds varies horizontally as well as vertically. In this respect they are like many fire clays.

SAMPLE X.
Graham's Brick Yard, Lenola, N. J.
From new road cut east of pit. Sample taken 10/10/29. Somewhat lower down than IXb, but exact distance difficult to measure. Estimated to be 10 feet lower.

Appearance: A greenish black clay with a gritty feel. Glauconite visible clearly with unaided eye.
Percentage of grade sizes....See strip diagram, Lenola, Sample X.

Mineral content: (Listed in order of abundance) Glauconite and quartz, abundant. Chlorite and muscovite, scarce. Heavy minerals (about 2% of the whole), they include hornblende, ilmenite, garnet, black tourmaline, manganese nodules, and one mineral not identified.

The outstanding characteristic of this sample was the great abundance of glauconite, there being between 40 and 45% glauconite in this sample; more than appears in any other sample of the Lenola section. The writer believes that here, locally at least, is a third glauconitic bed in the Merchantville formation. It is located

about thirty feet from the top, and lies beneath the upper glauconitic bed mentioned in many reports (Sample V), and is not near enough to the bottom of the formation to be the bottom glauconitic horizon.*

The Samples from Merchantville, N. J.

The Pennsylvania railroad cut on the eastern edge of the town of Merchantville is the type locality for the Merchantville clay. The formation is not entirely exposed here, only the upper 27 feet being visible. Two samples were taken in the railroad cut; samples with the most outstanding characteristics, and sufficiently different in color and texture to be easily separated from each other. Erosion and wash on the sides of the cut made it less easy to get good samples here than at Lenola, where fresh surfaces were continually being exposed by digging operations.

SAMPLE I.

Railroad cut, Merchantville, N. J.
9 feet from top of cut.

Appearance: Light chocolate-colored clay, deeply iron stained, varies in spots to browns and yellows; quartz and mica visible to the unaided eye.

Percentage of grade sizes,

See strip diagram, Merchantville, Sample I.

Mineral content: Quartz and mica most abundant; limonite and glauconite plentiful; scarcely any dark, heavy minerals seen; manganese nodules and fibers of supposed organic material, present but very scarce.

The glauconite in this sample is undergoing extensive alteration to limonite, and the writer believes is probably the source of most of the limonite in this bed.

No unusual features except the great abundance of quartz and mica. The quartz was angular to subangular, and clear. This was an unusually clean separation, therefore the high percent of grade 5 material is not all due to colloidal substance, but partly to the fact

*U. S. Geol. Surv., Folio of the Philadelphia Region.

that all the fines were properly located in the No. 5 group.

SAMPLE II.
Railroad cut, Merchantville, N. J.
15 feet from top of cut.

Appearance: Rubbery blue-black clay, resembling the lowermost beds of the Lenola section.
Percentage of grade sizes,

See strip diagram, Merchantville, Sample II.

Mineral content: Quartz, glauconite, muscovite, limonite (crusts and fragments), hornblende, and one dark mineral in grade size No. 4 which resembled biotite, but was in too small flakes to be properly identified.

Glauconite percentage of whole sample about 15%.

The clay was very high in colloidal matter, and lumped during the separation. Therefore the separation indicates possibly a too high content of grade sizes 1 and 3. Grade sizes 4 and 5 should be slightly increased at the expense of 1 and 3. But the writer believes that the diagram, taken in its entirety, is essentially correct.

Samples from the City Line Clay Pits, near Camden.

These samples were taken near the southern city line of Camden, N. J., in what is now the suburb of Woodlynne. The formation is exposed here in extensive clay pits which have been long abandoned, and the sides of which are now covered with soil which has washed down over them. The contact between the Merchantville and the underlying Magothy sand is said to be visible in these pits, but the writer could find no trace of it, although a diligent search was made. In the lowest pits a bottom layer of whitish sand was discovered, which had all the more obvious characteristics of the Magothy, but the sides and bottom of the pits were so thickly covered with slope wash deposits that the contact was invisible.

SAMPLE I.
City Line, Camden, N. J.
About 3 ft. below top of bank on west side of pit.

Appearance: A light brown to yellow, sandy clay.
Percentage of grade sizes,

See strip diagram, City Line, Camden, Sample I.

Mineral content: (Listed in order of abundance) Quartz, glauconite, muscovite, feldspar, limonite crusts and fragments.

A few scales of specular hematite were seen in grade size No. 2.

Glauconite content not more than 7% of the whole.

The quartz was in part subangular, and apparently the surface of some grains had been etched with some solvent. The majority of the quartz, however, was the typical clear, sharp grains that have been most abundant in the preceding analyses. Two quartz grains were observed which appeared to have been rounded by wind action, their surfaces being distinctly frosted.

Feldspar was present in very small quantities in the first three grade sizes. It was not orthoclase, but very possibly oligoclase.

The glauconite grains were much worn, as though they had either undergone transportation for some distance or received more working by waves and currents. This fact, together with the very small quantity of glauconite here, would point to an outside origin for the glauconite in this layer. The subangular quartz grains might have been carried a greater distance, also, than the sharply angular ones.

The high percentage of grade size No. 3, and the facts above noted, point to a shallow water environment at the time and place when this layer was being deposited.

SAMPLE II.
City Line, Camden, New Jersey.
Directly below Sample I, which merges gradually into Sample II.

Appearance: A dark, blue-black clay, with visible mica and glauconite. A clay quite fine in texture.
Percentage of grade sizes,

See strip diagram, Sample II, City Line, Camden.

Mineral content: (Listed in order of abundance) Quartz, muscovite, glauconite and chlorite are most abundant. Manganese nodules and crusts (?), feldspar, and a very few fragments of tourmaline

crystals, all quite scarce.

Both the subangular and sharply angular grains of quartz are present.

The glauconite is all of a very light green color, and quite worn. Much of it has begun to alter to limonite, judging from its color. Some grains are changing to the substance resembling chlorite, mentioned in connection with Sample III, in the Lenola section.

The glauconite percentage is unusually low in this sample, it being not over ten per cent. This, together with the small amount of coarse quartz and the large amount of mica, is probably the reason for the fine, soft texture of this clay. It is decidedly finer than the rest of the black clay samples.

SAMPLE I.
From ½ mile east of Fieldboro,
Burlington Co., New Jersey.
Church Brick Co.'s pit.

Appearance: A black, greasy clay containing much mica, but with no visible glauconite.

Mineral content: Essentially like that of the preceding sample, even to the worn and rounded lumps of glauconite. Feldspar, however, was not noted, nor were any tourmaline crystals, but both of these could have been present in such small quantities as to be easily missed.

Manganese nodules and what appear to be flakes of manganese oxide are present in this sample, as they also were in the preceding one.

From every point of view there is a striking similarity between the black layers in the upper section of the Merchantville clay at City Line, Camden, and at Fieldboro, Burlington County. They both suggest deposition in a basin under quiet conditions, and sluggish circulation of water. Apparently glauconite was either brought in from an outside source, or at least was not formed under these conditions as extensively as it has apparently been formed in other samples of the Merchantville clay which we have examined.

CONCLUSIONS

The Merchantville clay is a mixed deposit, incompletely sorted by wave and tidal action. This is suggested by the wide range in grade sizes and the fact that no prominent maximum percentage of any one grade size stands far above the rest, which is the case with well sorted deposits. That sorting action has not been prolonged is also indicated by the presence of angular quartz grains in every sample.

The lack of extensive sorting, and the presence of a considerable amount of organic matter suggest a lagoon deposit, more or less cut off from the open sea.

It has been suggested that the Merchantville is a delta deposit. But the persistence of the beds, their uninterrupted character, the fact that they change but little either vertically or horizontally, showing no rapid alternation of coarse and fine layers, no lensing out of individual beds, all point to a wide area of sea floor where conditions of sedimentations were but little disturbed.

Concerning the Glauconite

The glauconite in the Merchantville clay cannot be definitely connected with organisms. The writer searched diligently for any grains that could certainly be identified as foraminifer casts, and found only two, and they could have been the result of the accidental resemblance to foraminifer casts of a group of botyroidal lumps of glauconite.

The color of glauconite as an indicator of its possible age, has been suggested by several authors. It is believed by the writer that color as an indicator of age is a doubtful criterion. Early glauconites, Paleozoic, for example, are said to be in general lighter in color than the Cretaceous and Tertiary glauconites, which are dark green. The writer has observed every variation in light to dark greens in a single sample of the Merchantville, and in some samples various shades of yellowish green, brown, greenish brown, etc., are seen in a single grade size, depending on the degree of alteration. The light green grains were generally of a soft, wax-like consistency, as were

the brownish ones.

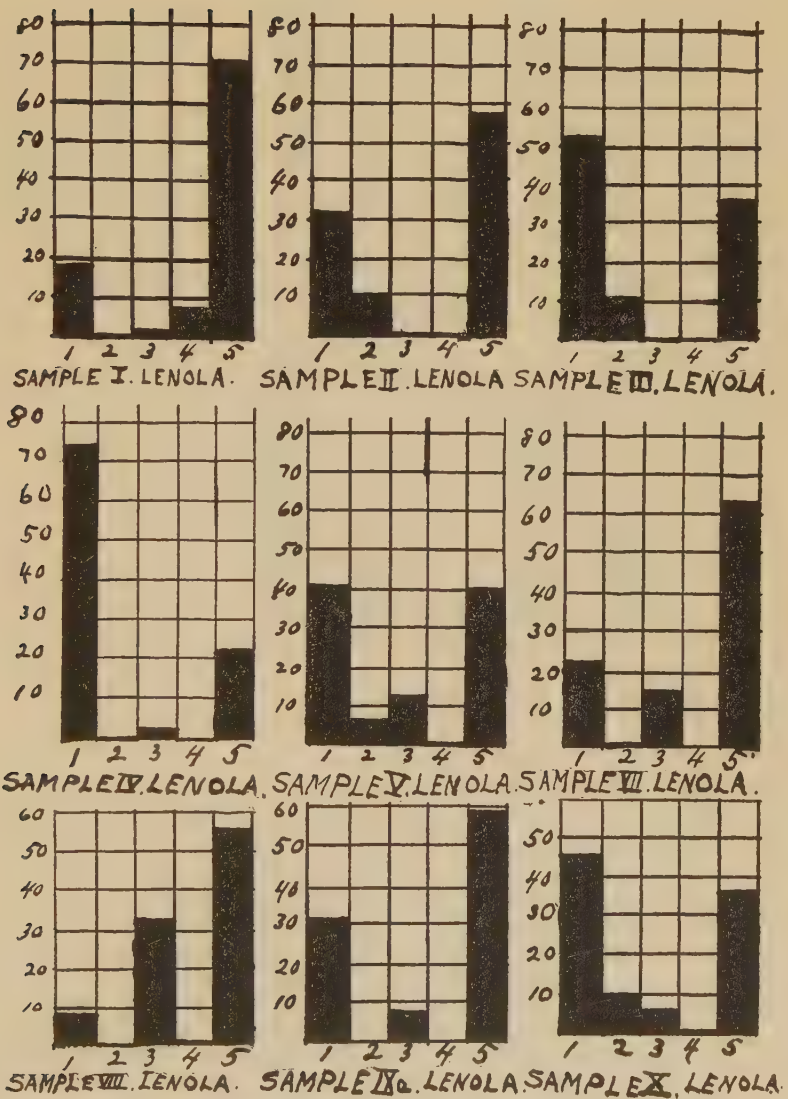
Glauconite is altering to limonite in some grains, and to a soft, platy, greenish mineral of wax-like consistency in others. This material resembles chlorite in appearance more than anything else. It is noted that the tendency toward the formation of flakes resembling chlorite was strongest in the glauconite which showed laminated structure. The individual laminae appeared to split off parallel to the base of what might be called a glauconite prism.

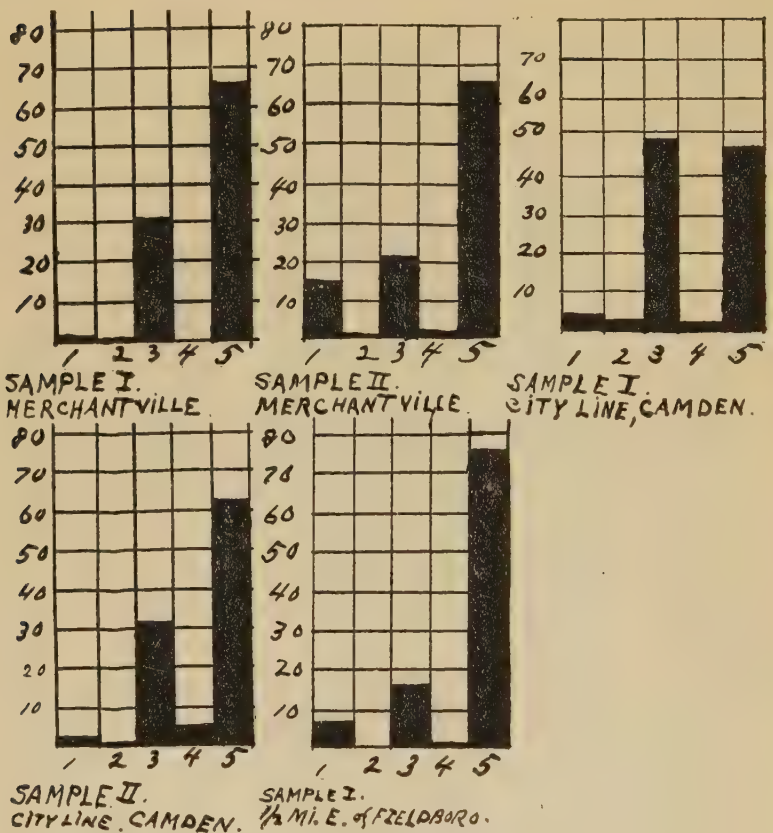
Glauconite alters to limonite also. It is the writer's opinion that the seam of limonite represented by sample IV, Lenola, and other similar occurrences reported by clay diggers as of local and fairly frequent occurrence in the Merchantville formation, are due, in a great measure, to the decomposition of glauconite. Careful observation of sample IV under the microscope showed gradual transition from grains partly changed to limonite to masses of limonite in which the outlines of completely altered grains were still visible.

The writer ventures the suggestion that a great deal of the limonite so prevalent in the younger formations near the surface throughout southern New Jersey, is derived from the decomposition of glauconite.

Two rather well defined beds of glauconite accumulations have been noted by various observers within the Merchantville clay, one close to the top of the formation, and the other towards the bottom.

The writer noted in addition to these, a bed of high glauconite content about thirty feet from the top of the Lenola section. It was not exposed until October, 1929, when a new road was cut through the Graham Brick Yard property.


SAMPLE I. LENOLA.
SAMPLE II. LENOLA
SAMPLE III. LENOLA.
SAMPLE IV. LENOLA.
SAMPLE V. LENOLA.
SAMPLE VI. LENOLA.
SAMPLE VII. LENOLA.
SAMPLE IX. LENOLA.
SAMPLE X. LENOLA.



Percentages by weight.....Read vertically
Grade sizes.....Read horizontally
No. 1—diameter in mm..... .3 mm. and over
No. 2— " " " ...Less than .3 mm. and over .2 mm.
No. 3— " " " ...Less than .2 mm. and over .16 mm.
No. 4— " " " ...Less than .16 mm. and over .12 mm.
No. 5— " " " ...Less than .12 mm. and over .02 mm.
No. 5 also includes any grains less than .02, and also material of colloidal fineness.

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